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16. ABSTRACT

It is hardly news today to point out that a lot of people are interested in highways, and it is not especially surprising that different individuals and groups are interested in different things about highways. First, there is the average citizen, all of the seventy-five million who drive automobiles. While John Citizen and his wife have the privilege of paying directly or indirectly for all of the highways, his requirements and preferences are rather simple and easily stated; a paved road surface free from dust or mud, long enough to reach from where her is to where he wishes to go, wide enough so that he can travel with comparative ease and smooth enough so that his moderately priced automobile will ride like the high priced luxury car that he cannot afford.

The operators of truck fleets and bus lines have similar ideas regarding length, width and riding qualities but they at times display some recognition of the fact that pavements must be something more than a surface even though there has been some "propaganda" tending to minimize the destructive effects of heavy axle loads and deploring any suggestion that trucks cause more damage to pavements than do automobiles.

To all intents and purposes however, most users of highways are aware only of the portion that they can see, and so far as the average individual is concerned a pavement is little more than a two dimensional facility. While most drivers may be aware that there are black pavements and white pavements, the first consideration is length, the second is width, and the third is surface roughness.

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STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

INFORMATION NEEDED
For The
STRUCTURAL DESIGN OF PAVEMENTS

By

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Materials and Research Engineer
California Division of Highways

56-02

Presented at the 35th Annual WASHO Conference
Phoenix, Arizona
April 10-11-12-13, 1956

April 2, 1956

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for the
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By

F. N. Hveem*

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Highway engineers, however, must think about a few other aspects such as cost, drainage, sight distance, the numerous geometric features associated with safety, and incidentally must give some thought to the structural design. This interest in structural factors has varied considerably throughout the years. The Romans, for example, gave to structural design a degree of emphasis that has never been equalled since. One cannot help but wonder today at the rugged construction and depth of cross section which was thought necessary for the Appian Way over 2,000 years ago.

Since the revival of highway engineering in modern times, interest in the structural section has waxed and waned throughout the years. Paving roads beyond the boundaries of incorporated cities was definitely a novel and intriguing idea fifty years ago and up to 1920 everyone was happy simply to get out of the mud and there was not much concern over the adequacy of the foundation and its ability to support the pavement. It was quite a shock to many to find that "massive pavements" 4" or even 6" thick over poor soils would not stand up under the increasing truck hauling developed during World War I. It was also learned the hard way that many old gravelled roads that seemed to be quite sound failed badly shortly after being covered with a bituminous pavement or surfacing. Between 1920 and 1930 therefore concern over repeated failures had built up to the point where a number of test highways were constructed in attempts to find out something of the principles that would dictate the strength and thickness of pavements or base that would be necessary. Interest in the structural aspects continued for some fifteen odd years but with the increased tempo of highway construction the time of chief engineers became more and more taken up with administrative problems, in fending off pressure groups and otherwise dealing with the broader aspects of the highway problem. With the increase in traffic more and more attention and thinking was devoted to legislation, financing, budgeting, access rights, planning, traffic analysis, et cetera, leaving proportionately fewer engineers to wonder about the structural adequacy of highway pavements.

However, with continually increasing industrial traffic and heavier loads, structural failures could no longer be ignored and again there was a revival of interest in test tracks or test highways. In addition to airfield test pavements constructed by the Corps of Engineers during the war years, in 1950-52 the Highway Research Board conducted a test of a concrete pavement in Maryland now known as Test Road One-MD. By 1955, the WASHO test track bituminous pavement project had been completed by the HRB and a report published. Now the states are engaged in the greatest cooperative test highway project ever conceived; namely, the AASHO test road in Central Illinois, which includes both portland cement and asphalt concrete. This project is estimated to cost nearly 12 million dollars and will require some six or seven years from the purchase of rights of way until the test data can be made available for use by the participating agencies.

All this seems to lead up to the question - What is it that we need to know that has prompted the construction of large and expensive test roads at this late day in highway construction? In fact, there are several questions. Perhaps the first and most obvious one would be - What can we hope to find out from any test highway project operated for only two years and limited to a few miles in a single locality. And the answer to this question should be compared to the answers to the much broader question - What does the engineer need to know in order to execute an intelligent design for the structural adequacy of pavements? Anyone familiar with the practical aspects of highway construction and maintenance and the limitations of small test projects can provide several obvious answers to the first question. A test track cannot provide realistic answers to construction costs on highways throughout the nation, maintenance or repair costs per mile on a test track can have little or no relation to maintenance expenditures per mile of actual highways. The relative costs or economy of the different size and types of vehicle used in motor truck transport can hardly be evaluated on a short relatively level test track free from intersections and interference from other traffic and with speeds restricted to 30 or 40 mph. The efficiency of geometric features such as the width, sight distance, curves, interchanges, et cetera, can only be evaluated by observing the effects on representative miscellaneous traffic that highways are designed to serve. Therefore, we may conclude that first cost, maintenance cost, efficiency and cost of vehicle operation, safety features, and effects of high speed are not susceptible to a solution by means of any test track thus far conceived. At best, we can only expect to learn something of the influence of the numerous variables that affect the structural adequacy of pavements.

Before commenting further upon the ability of test tracks to supply needed information, the next step is to examine the question of what is needed. In other words, what are the factors which an engineer must deal with in providing an engineering design for pavements? Most engineers recognize two distinct types of pavement and it is generally agreed that the principles, science and practice of construction are somewhat different for each. These pavements are commonly described as either "flexible" type or "rigid" type. There may be some ground for debate on this question of relative flexibility or rigidity, so to avoid misunderstanding, we will recognize that we are here talking about asphaltic pavements or portland cement concrete pavements. We will discuss first the factors that must be considered in the design of a typical asphaltic pavement.

Chart No. 1 is an attempt to subdivide the design problem into its separate components. There are, of course, several ways in which an analytical chart might be prepared. It seems, however, that just as the medical profession studies disease, we are forced to deal primarily with failures and the manifestations of failure. An adequate structural design consists merely of providing enough materials of a type and quality to prevent failure. If we have no failures, we have a structurally adequate pavement. It becomes evident that this problem of structural design is primarily a materials problem, and it is necessary in the proper analytical development to break down the primary factors to the point where the individual properties of materials can be measured or evaluated by some means. In other words, we must be able to assign a scale of values and a number to each of the important properties in order that we can recognize and deal with the effects <u>regardless of where encountered and regardless of the superficial appearance or local name of the particular terrain, horizon, soil, aggregate or asphalt involved</u>.

Referring to Chart, Fig. 1, the first column on the left indicates that we are concerned with failure and by inference how to prevent it. The failure of an asphalt pavement is made manifest by one or a combination of the three visible signs listed in column two. In other words, an asphalt pavement manifests failure either by cracking, by deforming, or by some degree of disintegration, or may even display evidence of all three types of failure simultaneously. The third column states that each of these manifestations or signs may depend upon or be caused by the traffic, by the pavement or the foundation separately, but usually acting in combination. As many of these terms are descriptive only and not capable of simple evaluation, these entities are further subdivided in column four where it appears that the destructive effects of traffic result from a combination of individual wheel loads, repetitions of these loads, by the area or distribution of the load and by the speed of the vehicles. In a similar break down, the pavement possesses some degree of stiffness, flexibility, durability, and so on, with other principal variables as shown in column four. Some of the items in column four are capable of direct evaluation; that is, they may be given an assigned number directly. For example, wheel loads may be determined by weighing the vehicle. Repetitions of wheel loads may be established by counting the number of vehicles and multiplying by the number of axles. However, we soon reach factors that must be further subdivided to permit simple evaluation. For example, the "area of load influence" is a term that actually reflects three variables which are listed in column five as tire contact area (which, with pneumatic tires, is approximately inversely proportional to the tire pressure) the number of tires, and the axle spacing. For vehicles in use today, axle spacing virtually resolves itself into the question of whether the trucks are equipped with single axles or tandem axles.

Proceeding to the fifth item in column four, that of pavement "stiffness," we find that it must be subdivided into secondary variables and finally into a tertiary group before we arrive at properties that can be directly measured or given a numerical value by means of tests. It will be noted therefore that this chart has been prepared on the principle of subdividing the factors or variables to the point where it is possible to assign a number and represent the particular factors or quality in a numerical scale of values. Column seven therefore lists the individual items indicating the manner in which each may be evaluated or tested. The various tests listed are not necessarily the only ones that might be used but the ones selected represent the opinion of the writer as to the best means available for measuring the properties listed. It will be found that there are at least 30 separate types of test or measurement for which the data or knowledge should be available. Actually, there are many more than these as several of the test methods are applied to different parts of the structure. These items then constitute the things which the engineer needs to know if he is to plan and design a pavement with an eye on each of the factors that may cause or contribute to trouble or structural failure. In order to determine the effect of variation in any one of these items or properties, experiments must be performed in which the factor is varied sufficiently to determine its influence and this usually means that an absolute minimum of three different values must be employed and in many cases the numbers should run into the thousands as in the case of load repetitions to determine the effects of variations in thickness of pavement, base or subbase layers.

It may be pertinent to examine some of the variables which have been provided in the initial plan submitted by the Working Committee for the AASHO test road. While at this writing, these plans are not necessarily final and may or may not be actually embodied in the test track, a consideration of the Working Committee proposal will serve to illustrate the point which is to recognize that all of the factors which affect only the structural adequacy of pavements cannot be explored even on a

12-million dollar test track occupying a strip of land over eight miles in length. Referring again to Figure 1, columns 8-9-10-11, it will be seen that the variables fall in two categories; those that can be controlled such as the traffic, and the uncontrolled such as the temperatures and rainfall. There is also a distinction between those that can be explored on the AASHO test track and the larger number that will not be investigated. Referring to the items listed numerically in column seven, we note that the plan provides for a variation in vehicle wheel loads. Four different single axle loads are scheduled and four different tandem axle loads. This number and range of load variations may be considered as reasonable and adequate as indicated in Column 11. The effect of load repetition will be observed up to the total number that will accumulate in about two years' time. No comprehensive program has yet been outlined to determine the effects of tire pressure or tire contact area, yet this variable may become of increasing importance to the highway engineer as trucks are now being equipped with tires capable of sustaining 150 psi or greater. As planned, the project will throw no light on the comparative effect of single tires versus dual tires. While all of the vehicles will be equipped with single tires on the front axle and dual tires on all others, no means have been provided to separate or evaluate the effects produced by single tires compared to dual tires. Item 5, axle spacing will be covered to a limited degree by operating half of the trucks with single axles and the other half with tandem axles. However, this means that we will have only a 4 foot spacing and a 15'+

spacing and this is not a sufficient variation to permit working out the laws that govern the influence of axle spacing. So far as highways are concerned, item four and five are perhaps not of pressing importance at the moment, but nevertheless we will still lack knowledge on the effects of varying the area of load influence such as might result from three or more axles spaced from four to eight feet apart. Item six refers to the speed, and no provision has been made for comparing the effects of vehicle speed which should include acceleration and deceleration. Because of limitations of the test track, all trucks will be operated at speeds approximately half that which is commonly developed on state highways.

Item seven refers to the consistency or grade of asphalt. Only one grade of asphalt is contemplated and the test track will not indicate whether there is any advantage in the use of softer or harder grades. Atmospheric temperatures and temperature of the pavement will vary throughout the life of the project but can not be controlled. The track will produce no evidence as to the optimum amount of asphalt which should be used. The mix will be designed according to some one of the current methods. It may well be that the ideal amount of asphalt is somewhat different for a pavement subjected to the heaviest wheel loads compared with one expected to carry much lighter traffic. The test track offers no opportunity to explore this variable. No variations in the gradation of the aggregate used in the asphalt pavement are contemplated.

We come now to item twelve, the question of slab thickness which is perhaps the most important variable that can be explored on a test track. All highways and streets today must be built with the assumption that they must carry one or more of the heaviest legal axle loads; this is true whether for quiet residential streets, a county road or an industrial highway. Therefore, the thickness for an adequate structural design need be varied only in respect to the number of load repetitions. If we plan to provide as we obviously should for as many repetitions of wheel load as can be developed on a test track, it is equally obvious that we should provide for as many different variations in slab thickness. We will be forced to develop the relationship between loads, repetitions and pavement strength factors by means of a relatively few loads over a short (2 years) space of time. As now planned portions of the track are heavier or stronger than the theoretical section that would be normal for a highway expected to serve for ten or twenty years. Any evaluation of the ultimate capacity of these heavier unfailed sections can be made only by extrapolating from the failures of the thinner sections which means that the only useful data will be derived from the sections that fail.

The number of sections that can be counted upon to fail may be not more than two for each wheel load.

Space will not permit a detailed discussion of all items, but the foregoing should serve to illustrate the comparison between "things we need to know" and those on which the AASHO test track may be expected to cast some light. The chart, Figure 1, indicates the relationships for Asphalt Pavements.

In the same manner Chart II is prepared to cover portland cement concrete pavements and it will be evident that there are many points of similarity in the primary factors but differences in some of the variables.

The comments on traffic are the same as for the asphalt pavement and similarly, there will be no provision on the test track to investigate the effects of differences in strength or composition of the concrete. There will be some comparison between different thickness of base and subbase but no evaluation of different types of base or subgrade treatments such as cement or asphalt is now planned.

Four thicknesses of concrete pavement are contemplated but only two sections on each loop have a reasonable prospect of failure within the two year test period. Therefore, any prediction of the ultimate capacity of the heavier pavements will in all likelihood have to be derived by extrapolation from the sections that do fail but extended projection from two or even three points is a rather dubious procedure when we consider the amount of money involved if we over design or under design the nation's highways.

This discussion is presented at this time with the feeling that those participating in the AASHO test track project should appreciate the scope and magnitude of the problems that must be solved in developing an adequate and economical structural design for pavements.

It also seems pertinent to point out how few variables will be investigated with any degree of thoroughness and that the relative behavior or potentialities of many types and varieties of road building materials will remain unexplored if the final design of the test track remains in substantially its present form.

Undoubtedly work on the project will be prosecuted vigorously and a vast amount of test data and field observations will be tabulated and accumulated for analysis and the final report. However, the Western States must in the meantime, continue to build highways and for the most part with materials and under conditions not represented on the test track in Illinois. We should continue to develop data and evidence of behavior on our Western Highways if we are to have intelligent solutions and efficient designs to meet the increasing heavy traffic. An increase in number and weight of vehicles is one of the few things that we can be sure of in the years to come.

In summary then, the engineer designing a modern pavement must be able to evaluate the traffic which he proposes to carry and, as the maximum wheel loads are established by law in most states, the problem of design for structural adequacy requires knowledge of what thickness and strength of materials are required to sustain the estimated number of wheel load repetitions (EWL). As traffic loads normally vary throughout a considerable range, we need some formula or device for converting all of the destructive effects of miscellaneous traffic into some equivalent unit in order that we can compare and evaluate the over-all destructive effect on the pavement. Similarly, we must be able to evaluate the capacity of the pavement in such terms as stiffness and degree of flexibility or the ability to resist fatigue failures. In turn, the foundation must be evaluated in terms of ability to assist the pavement to sustain loads; in fact the base or subbase is usually the primary factor so far as supporting loads is concerned.

It is not helpful or clarifying to say that any one element of a pavement structure is simply "good" or "poor". The foundation, for example, may contribute to stiffness of the base and subbase. It may have a high or low tendency toward plastic deformation. It may possess sufficient elastic deformation so that the pavement will ultimately be destroyed through flexing and fatigue. Nevertheless, adverse properties of the soil or base may be compensated for by complementary properties in the surface course.

Whether or not the engineer is fully aware of it, all of the factors shown on Fig. 1 and Fig. 2 must be developed to a sufficient degree if a pavement is to give satisfactory performance over a long period of time. The factors identified in the charts with the plus sign must be increased or built up beyond some minimum value. The factors indicated by the minus sign should not exceed the limits inherent in the individual pavement design.

So far as actual performance is concerned, it does not matter whether the structural relationships are arrived at by careful planning and design or are simply the result of chance. The pavement will perform equally well regardless of the means by which an adequate design was established. However, chance, guesswork and hoping for "the breaks" do not constitute engineering. Engineering is a science or profession that depends primarily upon the ability to establish numerical values for all factors concerned. In the case of pavement design, we must establish numbers for all of the variables involved if we propose to design pavements upon any basis better than guesswork or "experience". I offer Charts, Fig. 1 and Fig. 2, as an approximate outline of the information needed for the structural design of pavements.

OMIT THIS LINE
LEAVE 3/4" MINIMUM
BINDING MARGIN

REDUCE TO
11" EXACTLY

— = Ite
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